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SOME PRINCIPLES FOR ALLOCATING THE RADIO-FREQUENCY SPECTRUM AND FORMULATING PLANS FOR VARIOUS RADIO SERVICES

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SOME PRINCIPLES FOR ALLOCATING THE RADIO-FREQUENCY SPECTRUM AND FORMULATING PLANS FOR VARIOUS RADIO SERVICES

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ABSTRACT

Survey of the principles underlying the allocation of frequency bands for space radio communications and other radio services. Examples of the simultaneous use of the same frequency bands by radio, TV, and fixed and mobile services are cited. The methods used to define the necessary distance between ground stations for space communications and other services are examined.

Author

The rapid development of radio communications, the increase in radiated power, the increase in the sensitivity of receivers, and the inevitable combination of various radio services in common frequency bands, together with the resulting increase in mutual interferences between radio stations, have led to the necessity of an international control of frequency allocation and utilization. Even in 1903, eight years after the invention of radio, an /1*

*Numbers given in the margin indicate the pagination in the original foreign text.

international conference was held to consider the questions of controlling radio communications between ship and shore radio stations. It is interesting to note that among the delegates from Russia was A. S. Popov, the inventor of radio.

TABLE 1

Band No.	Range of Frequencies	Abbreviation	Corresponding Metric Subdivision
4	From 3 to 30kc	VLF-very low frequency	Myriameter waves
5	From 30 to 300kc	LF-low frequencies	Kilometer waves
6	From 300 to 3000kc	MF-middle frequencies	Hectometer waves
7	From 3 to 30 Mc	HF-high frequencies	Decameter waves
8	From 30 to 300Mc	VHF-very high frequencies	Meter waves
9	From 300 to 3000Mc	UHF-ultra-high frequencies	Decimeter waves
10	From 3 to 30 Gc	SHF-super high frequencies	Centimeter waves
11	From 30 to 300Gc	HHF-hyper-high frequencies	Millimeter waves
12	From 300 to 3000Gc (or 3 Tc)	-	Decimillimeter waves

Note: "Band No. N" covers from 0.3×10^N to 3×10^N cps.

Abbreviations: c = cycles per second; k = kilo (10^3), M = mega (10^6), G = Giga (10^9), T = terra (10^{12}).

With the development of radio communications, the allocated radio frequency spectrum had also expanded: in 1927 the spectrum allocated to radio communication was from 10 to 60,000 kc. A modern table of radio frequency allocations covers a range from 10 kc to 40 Gc. The radio frequency spectrum is subdivided into 9 frequency bands (table 1 (ref. 1)). /2

The table showing the allocation of frequency bands includes the following basic radio services:

- Fixed (surface communication, radio relay communication lines, and others);
- Mobile (surface, air and sea);
- Broadcast (including television);
- Radio navigation (air, sea);
- Cosmic radio communication (communication satellites, meteorlogical satellites, navigation satellites, space investigations and others);
- Radio astronomy;
- Radio amateurs and others.

In order to provide for an economic utilization of the radio frequency spectrum it has become necessary to classify radio communication service according to the nature of their work and to establish standards for the basic parameters of radio frequency radiations, such as:

- Radiated power;
- Radiated band width;
- Frequency stability;
- Side-band and extra-band radiation and others.

Most of the frequency bands in the table are shared, i.e., they permit a simultaneous operation of 2, 3, 4 and more radio services.

In the international regulations for radio cummunication the number of frequency bands shared by different services exceeds 80 percent. We should bear in mind that the combinations of shared frequencies are rather different, for example: (1) broadcast and radio navigation; (2) fixed, sea, mobile radio navigation; (3) space radio communication, fixed, mobile, etc. There is a total of 30 different combinations of frequency sharing.

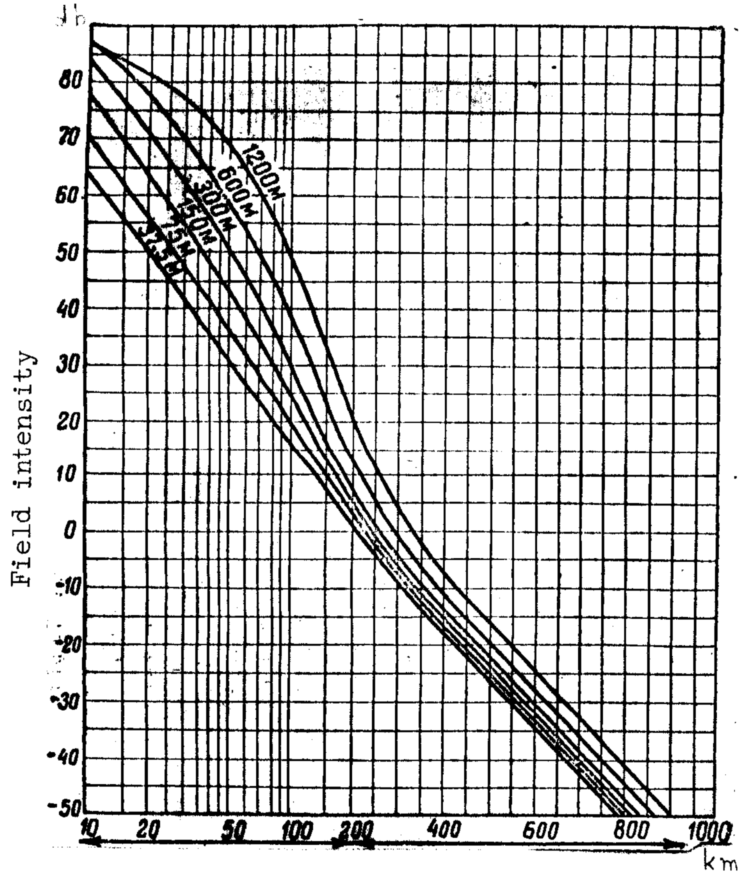
In the sharing of one band by several radio services the category of frequency allocation for each radio service is indicated (primary, secondary, etc.) and their rights are specified (service with primary allocation commands a priority).

In order to eliminate mutual interference between individual services and radio stations it has become necessary to prepare plans for the allocation of frequency channels to each station not only within the limits of one nation but also on an international scale. Such services include broadcasting, television, air and sea mobile service, etc.

In recent years a series of complex scientific and engineering problems have been solved which make it possible for important radio services to share frequency bands. Let us consider some of these services.

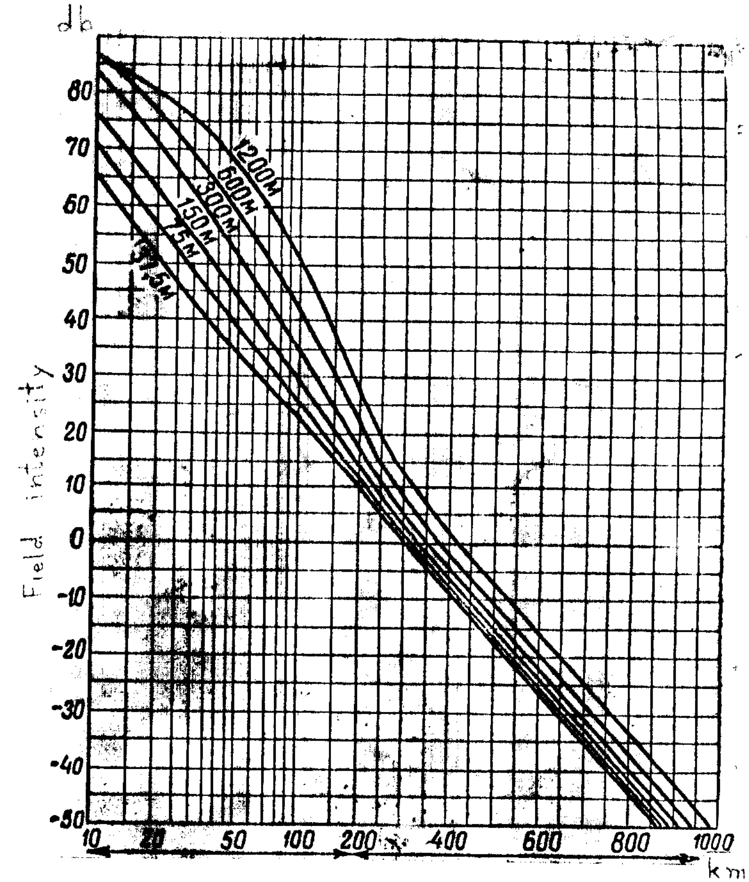
1. A sharing of frequencies by the broadcast services and the fixed and mobile services.

One of the examples of a complex combination of various services in one frequency range is the combination of powerful VHF broadcast stations and television stations with low power fixed and mobile services in the bands 68-73 Mc and 76-87.5 Mc. In the USSR and in several European countries these bands are used for FM broadcasts and television; in other nations they are used for fixed and mobile radio stations.



Logarithmic scale Linear scale
Distance

Figure 1



Logarithmic scale Linear scale
Distance

Figure 2

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In order to prepare a coordinated plan for the sharing of frequencies in the bands 68-73 Mc and 76-87.5 Mc by broadcast and television services with fixed and mobile services, it was necessary to solve a large number of scientific and technical problems and to conduct a large number of experiments (refs. 2, 3, 4). As a result of this it has become possible to prepare a plan for the sharing of the frequencies in this range by various services (ref. 5).

Figures 1, 2 and 3 show the variation in field intensity as a function of distance for 50 percent of the reception areas during a period of 50, 10 and 1 percent of the observation time respectively for various altitudes of the transmitting antenna when the altitude of the receiving antenna was 10 meters. The field intensity is expressed in decibels relative to one microvolt/meter for one kwt of effective power radiated by a half-wave dipole.

The effect of transmitting and receiving antenna height on the field intensity within the limits of the radio horizon may be determined approximately by the following equation:

$$X' = X + 70 - 4{,}1\sqrt{h'},$$

where

$$\sqrt{h'} = \sqrt{h_1} - \sqrt{h_2} - \sqrt{10}.$$

In this equation: X' is the corrected distance taking into account the height of transmitting and receiving antennas, X is the true distance, h_1 is the height of the transmitting antenna, h_2 is the height of the receiving antenna.

To determine the field intensity of the received signals for different heights of the transmitting and receiving antennas it is necessary to compute the distance X from the distribution curves for transmitting antenna height

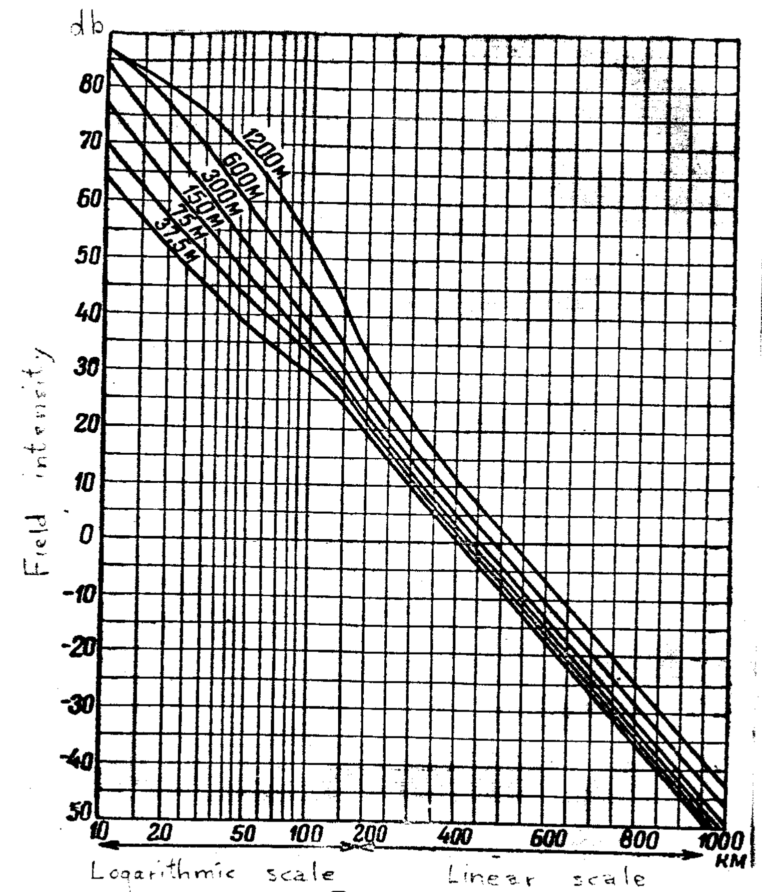

Figure 3

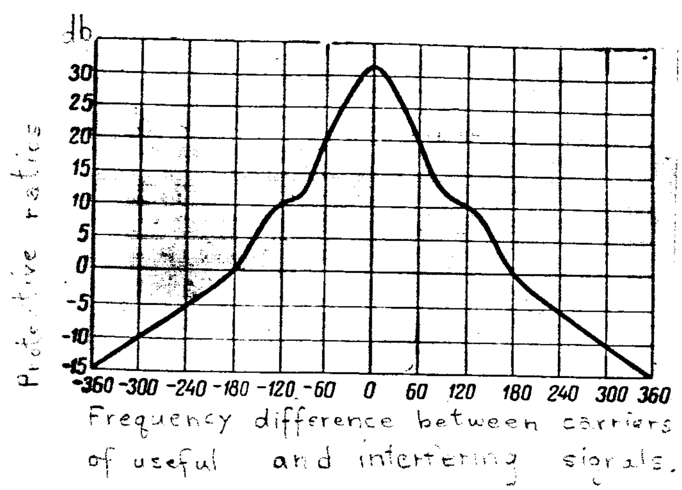

Figure 4

$h_1 = 300m$ and receiving antenna height $h_2 = 10m$; then from the equation the distance X' can be determined for other heights of the transmitting and receiving antennas for which the field instensity corresponding to the quantity X with $h_1 = 300m$ and $h_2 = 10m$ is retained.

Interference protection ratios required for fixed and mobile services utilizing frequency modulation with deviation up to ± 15 kc if the interfering signal is an FM broadcast signal with a deviation ± 50 kc, are shown by the curve in figure 5. Curve 1 is applicable to receivers designed for a channel separation of 50 kc while curve 2 is for receivers with channel separation of 25 kc.

The curve for interference protection ratios shown in figure 6 (television system with a scan of 625 lines) is used to determine the interference protection when the interfering signal is an FM signal from a fixed or mobile service station. In cases of an AM signal the interference protection ratio should be increased by 5 db.

This curve can be used only in a black and white television system, because corresponding data relative to interference protection required by color television are not available to date. We can assume that the interference

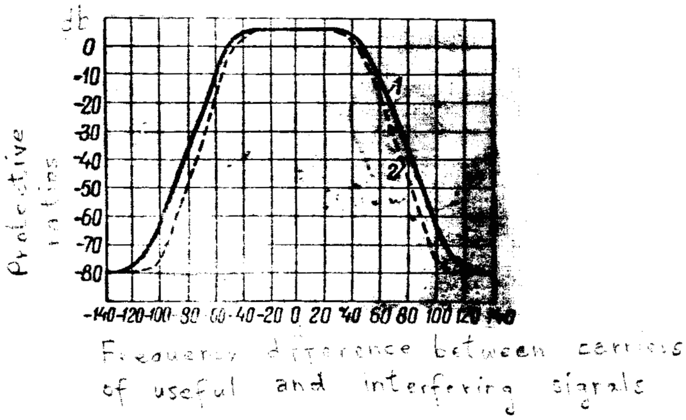

Figure 5

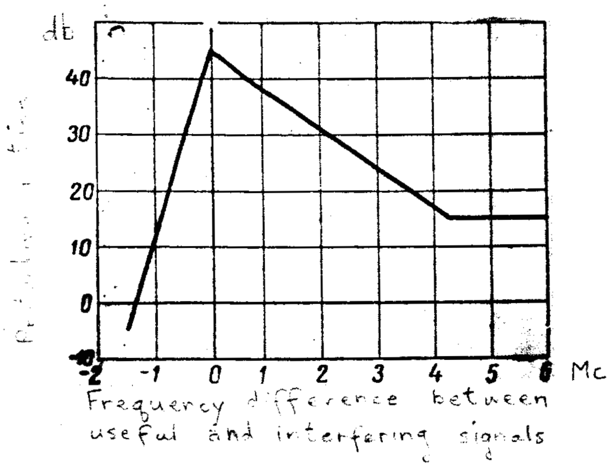

Figure 6

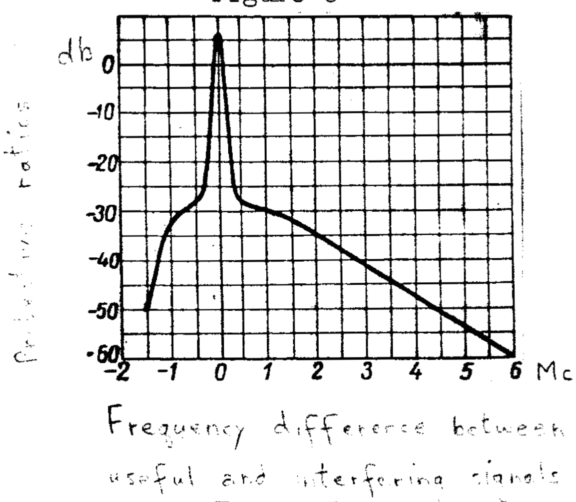

Figure 7

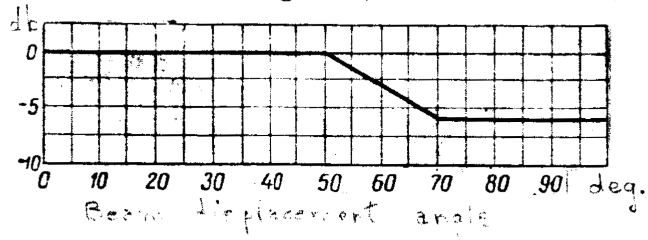

Figure 8

protection required for color television will be substantially greater than shown in figure 6, in the region of the color sub-carrier frequency.

The interference protection ratio required for fixed and mobile stations /6 operating with FM is shown by the curve in figure 7 if the interfering signal is from a television station with an image scan of 625 lines.

The interference protection required for fixed and mobile radio stations from the television voice channel is the same as the one assumed for protection from FM broadcasts.

The minimum protected field intensity under different conditions which is necessary for reception in the presence of noise is as follows:

For FM broadcast: 0.25 millivolt/per meter in the general case;

1 millivolt per meter in municipal regions where the level of industrial interference is high;

3 millivolts per meter in large cities where industrial interference is extremely high.

For television: 0.5 millivolt per meter in towns;

2 millivolts per meter in cities.

For Fixed and Mobile services: 5 microvolts per meter in towns where the level of industrial interference is low;

10 microvolts per meter in towns and cities where the level of industrial interference is high;

20 microvolts per meter in cities where the level of industrial interference is very high.

Plans for mobile services and FM broadcasting services do not take into account the additional protection achieved by the use of directional receiving antennas.

Television receivers usually use simple directional antennas; therefore, an additional protection up to 6db is taken into account during planning in accordance with the curve shown in figure 8. In cases where television and FM broadcast stations use directional transmitting antennas, an additional protection up to 15 db is taken into account.

In fixed services the utilization of directional antennas is also taken /7 into account. These provide an additional protection of at least 6db.

All of the services use different polarization; in this case and additional protection of 10db is applied at 90 percent of the reception areas.

2. Determining the frequency bands for cosmic radio communication.

The launching of the first Earth satellite, developed in the USSR, on 4 October 1957, has opened a new era in the history of mankind.

In the subsequent period a great deal of success has been achieved in conquering space: photography of the far side of the moon and transmission of the images to Earth, location of the Moon, of Venus and Mars; radio communication between two spacecraft and also the first television transmission from space, radio communication between nations and continents by means of artificial Earth satellites, and others.

To solve these problems it was necessary to allocate the necessary number of frequency bands to the various space services. The frequency bands had to be selected in such a way so that on the one hand they would further the conquest of space and on the other would not interfere with existing radio communications systems.

From the point of view of frequency utilization, space radio communications may be divided into 3 basic categories:

(1) Space investigation;

(2) Operational communications systems utilizing artificial earth satellites (communication satellites, meteorlogical satellites and navigation satellites);

(3) Service communications (telemetery, tracking, remote control).

The selection of the optimum frequency for any category of space radio communication depends on many factors including the propogation and attenuation of radio waves, levels of external interference, etc.

Since the basic "consumers" of radio frequencies (from the standpoint of bandwidth) are the communications systems which use the artificial Earth satellites as relay stations for the radio signals, all subsequent discussions will be concerned with communications satellites.

Since the prospective communication systems utilizing artificial Earth satellites must be designed to transmit wide band information (television, hundreds of telephone conversations, etc.), it becomes obvious that super high frequencies must be used in such systems.

To select the most expedient frequency range we consider the variation in the intensity of external noise as a function of frequency.

Figure 9 presents a graph which shows the noise level as a function of /8
frequency and elevation of the receiving antenna (ref. 6). The minimum

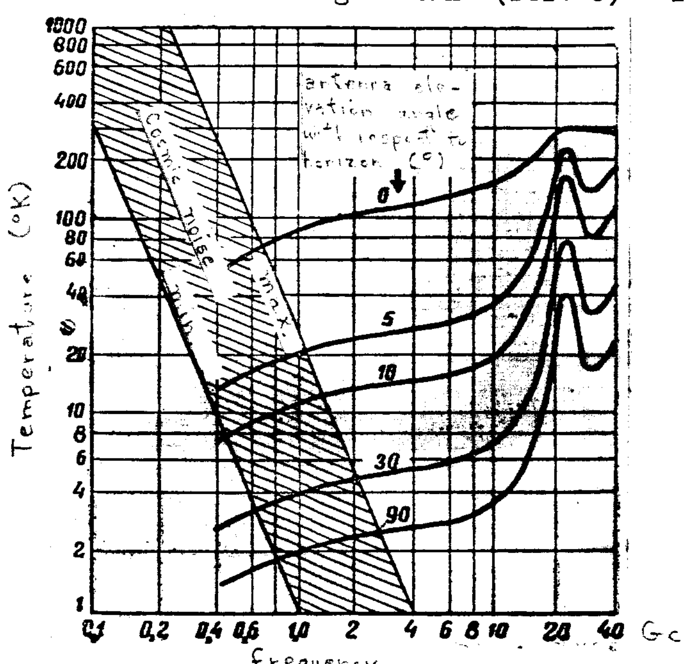

Figure 9

external noise is recorded in the range from approximately 3 to 10 Gc. At higher frequencies there is an increase in atmospheric noise (due to the absorbtion by oxygen and water vapor), while in the region of lower frequencies space noise becomes noticeable.

The elevation of the receiving antenna is important from the standpoint of reducing external noise. External noise is substantially reduced when the elevation angle of the receiving antenna exceeds 5 degrees.

As we have already pointed out, the entire spectrum of frequencies from 10 kc to 40 Gc is allocated to different radio services. Consequently, in communication systems utilizing artificial Earth satellites the frequency band can be allocated only on a shared basis with other existing radio services.

From the engineering standpoint it is very simple to have the communication systems utilizing artificial Earth satellites share frequency with the line of sight radio relay stations: the latter as a rule use a frequency band from 3 to 10 Gc. To reduce mutual interference between services using the same frequency band it is necessary to place certain limits on the power of these stations.

Conditions for such combined operations are as follows: (refs. 4, 7):

(a) The density of the power flux at the surface of the Earth produced by the radiations of a cummunication satellite using frequency or phase modulation with high frequency deviation must not exceed -130 db·watt/m^2 for all angles of incidence. In addition to this such signals if necessary must be continously modulated by a signal of corresponding form so that the flux density does not exceed -149 db·watt/m^2 in any 4 kc band for all angles of incidence.

(b) The power flux density at the surface of the arth produced by communication satellites which use other than frequency of phase modulation with high frequency deviation must not exceed -152 db·watts/m^2 in any 4 kc band for all angles of incidence.

(c) The level of the average effective power generated by the ground station associated with the communication satellite in any direction in the horizontal plane must not exceed +55 db·watts in any 4 kc band. The transmitting antennas of the ground stations must not have an elevation angle less than 3 degrees; the angle is measured between the horizontal plane and the central axis of the principle lobe.

(d) The maximum effective power radiated by the transmitting antenna of fixed or mobile service must not exceed +55 db·watt while the power supplied to the input of the antenna from any such transmitter must not exceed +13 db·watts.

In addition to this we must also take into account the possibility of interference between fixed or mobile ground stations and the ground stations for space radio communications when such stations are close together. Under these conditions it is necessary to coordinate the allocation of frequency on an international basis.

The mutual interference between stations of different services will depend on several factors: the power of the transmitters, the gain of the antennas in the direction of interference propagation, the nature of the surrounding region, the permissible level of interfering signals at the input of the receivers. Since the distance beyond which mutual interference may be considered insignificant depends on the propagation of radio waves, the conditions of such /9 propogation are taken into account when this distance is computed.

To determine this distance it is necessary to know the minimum permissible basic attenuation during the propagation of radio waves (L_b), which can be obtained from the equation

$$L_b = (P_t + G_t) - F_s - (P_r - G_r),$$

where P_t is the power in db·watts supplied by the interfering transmitter to the input of the transmitting antenna, G_t is the gain of the transmitting antenna of the interfering station in the direction of the receiving station in db, F_s is the screening coefficient of the region surrounding the ground station in db, P_r is the maximum permissible level of interference at the input of the receiver at the receiving station in db·watts, G_r is the gain of the receiving antenna in the direction of the interfering transmitter in db.

TABLE 2

θ	F_5
Below 1^o	0
Between 1 & 2^o	5
Between 2 & 3^o	8
Between 3 & 4^o	11
Between 4 & 5^o	13
Above 5^o	15

The variation in F_s as a function of the elevation angle (θ) at which the obstacle is observed from the ground station is shown in table 2. If the obstacle is situated at a distance less than 5 kilometers the necessary values of F_s can be obtained by multiplying the data shown in the table by d/5, where d is the distance from the ground station to the obstacle in kilometers.

Data on propagation presented in the subsequent figures pertain to a frequency of 4 Gc. Therefore, before using them to determine the interference distance it is necessary to transform the minimum permissible basic attenuation during propagation (L_b) into an equivalent attenuation at a frequency of 4 Gc (L_{b1}).

The equivalent attenuation in db at frequencies 4 Gc is determined from the equation

$$L_{b1} = L_b + 13 - 21.6 \log f,$$

where f is the appropriated frequency in Gc.

This relationship is shown graphically in figure 10.

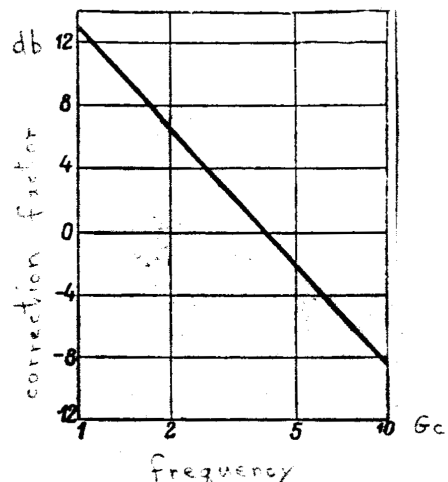

Figure 10

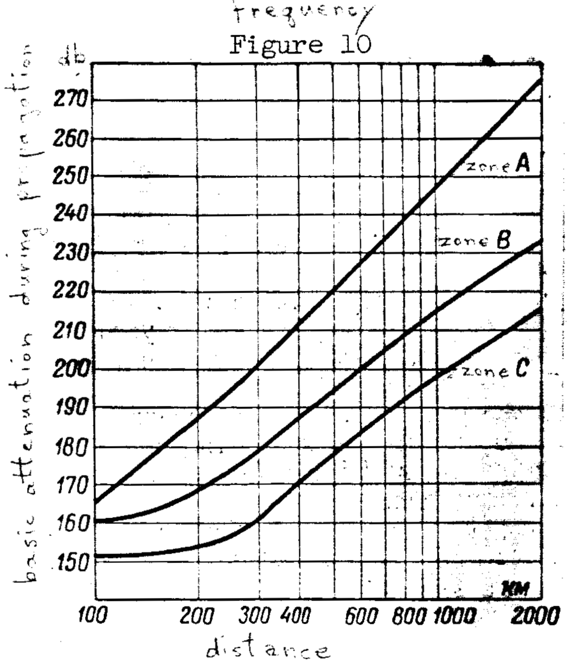

Figure 11

Figure 11 shows the simplified curves of tropospheric propagation for computing the interference distance in the case when the basic attenuation is not exceeded during 0.1 percent of the time. Zone A corresponds to propagation conditions over land; zone B corresponds to propagation over the ocean at latitudes greater than 23.5° N and 23.5° S; zone C corresponds to propagation over the ocean at latitudes between 23.5° N and 23.5° S inclusive.

In any direction from the ground station the necessary interference distance is determined in the following manner:

(1) If L_{b1}, the basic equivalent attenuation during propagation, is such that the interference distance in a given direction lies entirely within one of the zones, then it can be obtained directly from the curve in figure 11; /10

(2) If the interference distance is partially in one zone and partially in another, it is necessary to use the curve for the combined runs (figures 12, 13 and 14). These curves show the variation in the attenuation

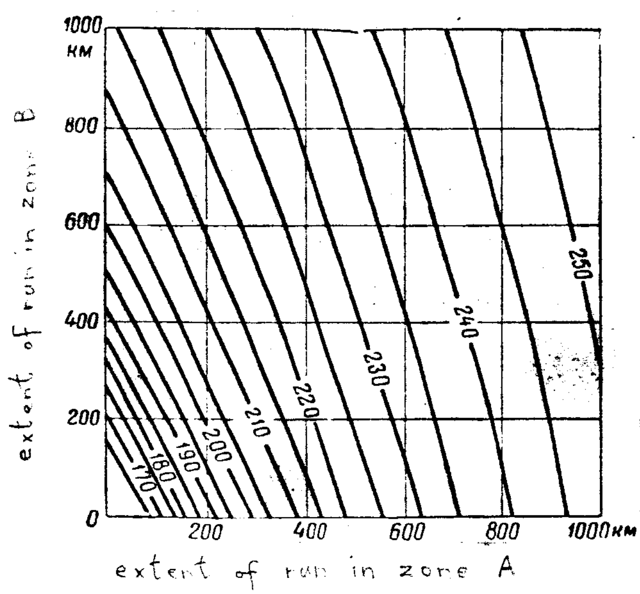

Figure 12

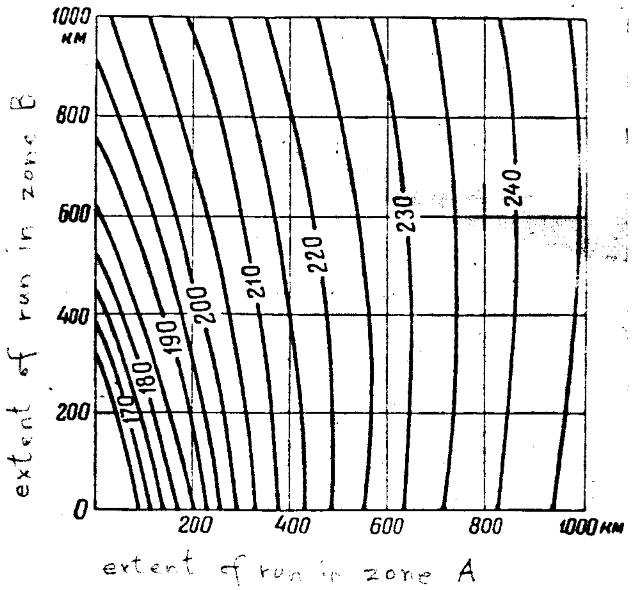

Figure 13

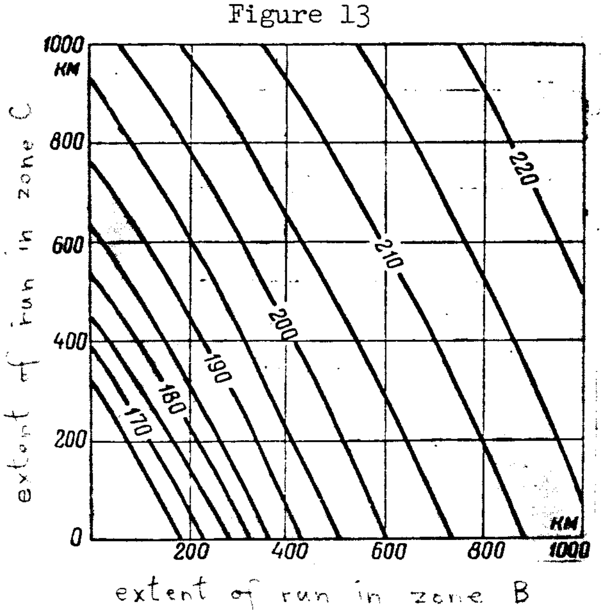

Figure 14

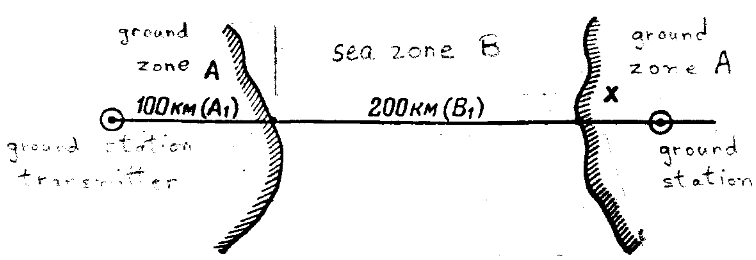

Figure 15

L_{b1} as a function of the run in each of the two zones independently. Thus, if the extent of the run is known in one zone, together with the acquired attenuation, the extent of the run in the other zone can be obtained.

Let us consider the case of determining the interference distance for a run shown in figure 15. Here the ground station is 100 kilometers from the shore line and the distance to the shore line of the adjoining country is 200 kilometers over the sea. Let us find the distance x from the shore line to /12 the ground station assuming that the attenuation between the stations must be equal to 195 db. This distance can be computed by using the graph shown in figure 12.

For convenience we copy the curve of this graph, corresponding to an attenuation of 195 db, in figure 16.

We make the following constructions in figure 16:

1. First on the A axis on the graph we plot the distance from the earth station to the shore line equal to 100 kilometers as shown by point A_1.

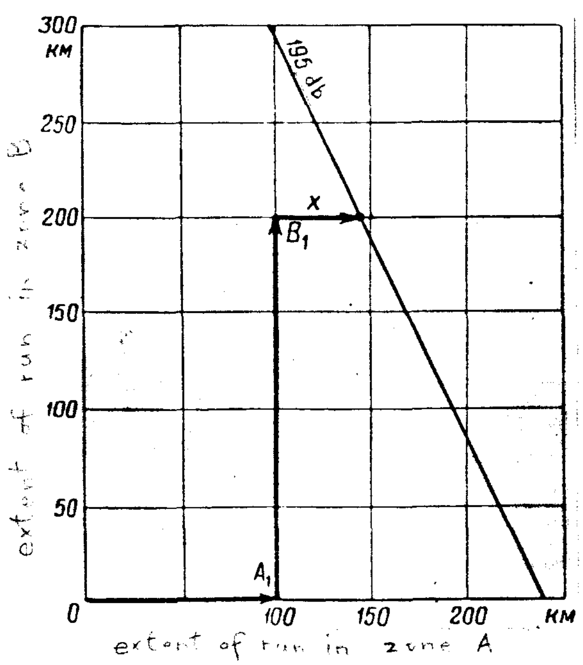

Figure 16

2. Then parallel to the B axis of the graph we plot the run of 200 kilometers over the sea as shown by the point B_1.

3. The unknown distance over the land is measured parallel to the A axis from point B_1 to the point of intersection with the 195 db curve as shown by x. We find that this distance is equal to 44 km.

4. Thus, the interference distance will equal 100 + 200 + 44 = 344 km.

Since the existing data are insufficiently accurate and the necessary experience in the operation of communication systems using artificial earth satellites has not been accumulated, the norms presented here and the method of calculation require further refinement.

REFERENCES

1. Regulations Covering Radio Communications (Reglament radiosvyazi) Geneva, 1959, Svyaz'izdat, 1961.
2. Sankin, N. M., and Trunov, V. I., The Principles for the Engineering Planning of TV Transmission Networks and UHF FM Broadcasting (Printsipy tekhnicheskogo planirovaniya peredayushchey seti televizionniogi i UKV ChM Vestchaniya), Svyaz'izdat, 1960.
3. The Method of Planning Television Networks and UHF FM Broadcasting (Metody planirovaniya setey televideniya i UKV ChM veschaniya), Dok. IV-9/58 TK OIRT, Budapest, 1958.
4. CCIR, Documents of the 10th Plenary Assembly, ITU, Geneva, 1963.
5. Final Acts, Special Regional Conference, ITU, Geneva, 1960.
6. Pierce, I. R. and Kompfner, R., Proc. Inst. Radio Engrs. March, 1959.
7. Final Acts of the Extraordinary Administrative Radio Conference to Allocate Frequency Bands for Space Radiocommunication Purposes. ITU, Geneva, 1963.